



Consolidated Development Objectives

Document (CDOD) For MB-60

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1. Introduction

This document defines the objectives related to liquid rocket engine system development to be undertaken by JAXA in support of the Space Launch System (SLS) Program managed out of the NASA Marshall Space Flight Center (MSFC). These objectives include furnishing the necessary management, labor, facilities, tools, equipment, and materials required to execute the specified activities.

1.1 Project Scope

The scope of this effort is to develop a rocket engine and associated products per the objectives and technical requirements established in this document. This engine, minus the engine controller, designated here as MB-60, is to be developed through to a pre-qualification point of maturity. It is assumed that should JCNE-1 development proceed beyond this maturity point towards actual flight qualification, the engine controller will be supplied and integrated by NASA.

1.2 Document Structure

The structure of this Consolidated Development Objectives Document (CDOD) includes a traditional description of objectives in a SOO, plus the associated Data Products Document (DPD) in an attached appendix, and then Engine Requirements Document (ERD) as another attached appendix. It is the intent that this document, in conjunction with the cited applicable documents, should constitute a complete programmatic and technical description of the development effort to be pursued.

1.3 Compliance Validation to Design Standards

As part of this CDOD, a handful of key design standards are cited to guide the design and construction of the MB-60. As compared to the usual set of applicable documents for a NASA rocket engine, this set is quite minimal. The intent is to focus on the key intrinsic aspects of the design to facilitate the possible transition from development and demonstration to actual flight qualification. Also, this set of standards is smaller than is typical due to the fact that it is assumed no engine controller work is included as part of the development effort.

The structure of this CDOD is intended to assist and simplify the compliance process. For each of the four key design and construction standards cited (NASA-STD-5012, NASA-STD-5017, NASA-STD-5019, and NASA-STD-6016), it is directed in the SOO that a meets-or-exceeds assessment be conducted against previous established practices. Then, for three of the four documents, it is directed that a compliance plan be written. The acceptance of this compliance plan is, effectively, the acknowledgment of the meets-or-exceeds assessment and the acceptance of tailoring to meet the intent of the

imposed standard. Finally, the associated products listed in the SOO address not only the engine development process but also, through environments descriptions and models validation, the path towards design requirements verification.

More can be discussed on this issue and the associated compliance process. However, the point to be expressed here is that the purpose of imposing these standards is not necessarily to override established practices. Rather, it is to understand these practices using a familiar and accepted comparative backdrop. Any changes to established practices will have to be the subject of further discussion and consideration.

1.4 Compliance to Other Standards

In addition to the four key design standards, there are a handful of other standards cited within this CDOD related primarily to products other than engine hardware design and construction. For these standards, no formal meets-or-exceeds assessments are called for in the SOO nor are there any requirements to generate compliance plans. The use of substitute standards or processes is acceptable after review and concurrence from NASA that these substitutes meet the intent of the imposed standard and that the use of an alternative standard would not result in undue difficulty should the MB-60 be considered for use and integration within a NASA program in the future.

2. Documents

2.1 Applicable Documents

This section contains documents specifically cited as applicable within this CDOD. The listed applicable documents and their contents form a part of the overall programmatic objectives and technical requirements set to the extent specified herein. Technical tailoring is described in the Compliance Validation section and the SOO as part of the overall compliance validation activity.

Document Number	Document Title	Revision	Date
Engine Design and Construction Standards			
NASA-STD-5012	Strength and Life Assessment Requirements for Liquid Fueled Space Propulsion System Engines	Baseline	Jun 2006
NASA-STD-5017	Design and Development Requirements for Mechanisms	Baseline	Jun 2006
NASA-STD-5019	Fracture Control Requirements for Spaceflight Hardware	Baseline	Jan 2008
NASA-STD-6016	Standard Materials and Processes Requirements for Spacecraft.	Baseline	Jul 2008
Environments Documentation			
[TBD]	Induced / External environments documentation		
Requirements and Standards for Technical Products			
ASME Y14.100-2004	Engineering Drawing Practices	-	2005
ASME Y14.41-2003	Digital Product Definition Data Practices	-	2003
MSFC-STD-3394	Standard for Contractor Configuration Management, MSFC Programs/Projects	A	Jan 2005
SLS-RQMT-014	Space Launch System (SLS) Program Safety and Mission Assurance Requirements	B	Jan 2013
SLS-RQMT-015	Space Launch System (SLS) Program Hazards Analysis Requirements	A	Jul 2012
SLS-RQMT-016	Space Launch System (SLS) Program Failure Modes and Effects Analysis / Critical Items List Requirements	A	Jul 2012

2.2 Reference Documents

This section contains documents cited as references within this CDOD. These are listed for guidance and information only.

Document Number	Document Title
AS9100	Quality Systems: Aviation, space & Defense Organizations
MIL-STD-961	Department of Defense Standard Practice for Defense Specifications
NASA-HDBK-5010	Fracture Control Implementation Handbook for Payloads, Experiments and Similar Hardware
NPR 7123.1	NASA Systems Engineering Processes and Requirements
NPR 8715.3	NASA Safety Manual

3. Statement of Objectives (S00)

This is the statement of objectives that provides the scope of the overall development activity for the MB-60 effort.

3.1. Program Management

Manage, plan, and coordinate the activities across all portions of the MB-60 work scope by providing direction for program administration, business management, and supplier management.

Provide for Quarterly Program Reviews (MPR) to NASA insight into the technical and programmatic progress, issues, risks, and forward plans for the development effort. Make available to NASA, upon request, current data and documentation related to this development effort.

3.2 Systems Engineering and Analysis

Manage and perform Systems Engineering and Analysis to provide rigor and structure to the overall design and development effort for the MB-60.

3.2.1 Milestone Reviews

Conduct milestone reviews during the MB-60 development effort including milestones equivalent to the following:

- System Requirements Review
- System Definition Review
- Preliminary Design Review
- Critical Design Review

The reference to use to assist in determining the scope and intent of these various reviews is NPR 7123.1.

Conduct a final closeout milestone review focused on development progress, requirements verification, model validation, and final forms of associated products.

3.2.2 Requirements Management

Develop, deliver, implement, and maintain the MB-60 System-level Specification per DRD SE-001, *Engine System Specification*, which is compliant with the MB-60 Engine Requirements Document (ERD) provided in Appendix C.

Perform and document meets-or-exceeds assessments of all design, development, construction, and workmanship standards imposed via technical requirements documentation. These assessments are to be consistent with the processes developed by NASA under the description of Compliance Validation.

Develop and deliver final verification compliance reports for the requirements contained in the MB-60 System-level Specification as described in DRD SE-002, *Verification Compliance Reports*.

3.2.3 System Analysis

Conduct and document trade studies to determine the appropriate engine configuration to meet all design specifications and to optimize overall engine attributes.

Develop, maintain, and mature throughout the life of the project an engine system balance, a mathematical representation of the steady-state performance characteristics across the MB-60 system.

Develop, maintain, and mature throughout the life of the project an engine system transient analysis model, a mathematical representation of the transient performance characteristics across the MB-60 system.

3.2.4 Program Management Support

Develop, deliver, implement, and maintain a Configuration Management Plan per DRD SE-003, *Configuration Management Plan*.

3.3 System Integration

Provide coordinated integration in the realms of engineering, safety, quality, and manufacturing disciplines across the scope of the MB-60 design and associated products development.

3.3.1 Safety and Mission Assurance

Develop, deliver, implement, and maintain a System Safety Plan per DRD SQR-001, *System Safety Plan (SSP)*.

Develop, deliver, implement, and maintain a Quality Assurance Plan per DRD SQR-002, *Quality Assurance Plan*. An element of the implementation of this plan is the maintenance of a problem reporting and corrective action system.

Develop, deliver, and maintain a fault tree-based hazards analysis for the MB-60 consistent with DRD SQR-003, *Hazards Analysis*.

Perform, document, and deliver Failure Modes and Effects Analysis (FMEA) for the MB-60 engine, and based on the results, develop and deliver a MB-60 Critical Items List (CIL) per DRD SQR-004, *Failure Modes and Effects Analysis and Critical Items List*.

Documents applicable to this section and products: SLS-RQMT-014, SLS-RQMT-015, and SLS-RQMT-016.

3.3.2 Structural Design

Develop, deliver, implement, and maintain a Structural Assessment Plan per DRD DE-001, *Structural Assessment Plan*.

Develop, deliver, and maintain structural strength and fatigue analysis reports per DRD DE-002, *Structural Strength and Fatigue Analysis Reports*.

Documents applicable to this section and products: NASA-STD-5012 and NASA-STD-5017.

3.3.3 Fracture Control

Develop, deliver, implement, and maintain a Fracture Control Plan per DRD DE-003, *Fracture Control Plan*.

Develop, deliver, and maintain fracture control analysis and reports per DRD DE-004, *Fracture Control Reports*.

Documents applicable to this section and products: NASA-STD-5019.

3.3.4 Materials and Processes

Develop, deliver, implement, and maintain a Materials and Processes Selection, Implementation and Control Plan per DRD DE-005, *Materials and Processes Selection, Implementation, and Control Plan*.

Develop, deliver, and maintain material and process identification and usage list per DRD DE-006, *Material and Process Identification and Usage List (MIUL)*.

Develop, deliver, and maintain material usage agreements per DRD DE-007, *Material Usage Agreements (MUAs)*.

Documents applicable to this section and products: NASA-STD-6016.

3.3.5 Thermal Analysis

Develop, deliver, and maintain thermal analysis models in support of the design and verification of the integrated MB-60. A part of this activity includes the development

and maintenance of a thermal design data book per DRD DE-008, *Thermal Design Data Book*.

3.4 System Development, Assembly, and Test

Manage the scope of the development, assembly, and test-related activities for MB-60 development. This scope includes engine-level development planning, engine assembly and disassembly, test planning, engine testing, inspection, anomaly resolution, and development of necessary ground support equipment and special test equipment.

Develop, deliver, and maintain a Propulsion System Development Plan per DRD DE-009, *Propulsion System Development Plan*.

Plan MB-60 system testing as outlined in the MB-60 Propulsion System Development Plan. As a part of this planning, define the test requirements matrix in support of requirements verification planning and analytical model validation.

Develop a test series report for each MB-60 system test series per DRD DE-010, *Engine System Test Reports*.

3.5 Hardware Design, Development, and Fabrication

Design, develop, and fabricate or procure MB-60 component hardware compliant with the imposed technical requirements and in sufficient quantities to fulfill the overall MB-60 development effort. The specific hardware categories include:

- Engine system hardware
 - Lines and ducts
 - Interconnect hardware
 - Gimbal structure
 - Ancillary systems
- Valves and actuators
 - Propellant valves and actuators
 - Ancillary system valves
 - Pneumatic system packages
- Avionics control systems
 - Harnesses
 - Instrumentation
- Turbomachinery
- Combustion Devices
 - Injector
 - Ignition systems
 - Combustion chamber
 - Nozzle

Note: It is assumed that an engine controller unit design will not be part of this development effort.

Provide MB-60 system-level, subsystem-level, component-level, and part-level definition data pertaining to engine system integration and hardware (e.g., drawings and associated lists) per DRD DE-011, *Product Definition Data and Associated Lists*.

APPENDIX A

Abbreviations Listing

Abbreviations and Acronyms

AML	Approved Materials List
APL	Approved Processes List
CAD	Computer-Aided Design
CDOD	Consolidated Development Objectives Document
CGM	Computer Graphics Metafile
CID	Cable Interconnect Diagram
CIL	Critical Item List
DPD	Data Procurement Document
DRD	Data Requirements Description
ERD	Engine Requirements Document
FMEA	Failure Modes and Effects Analysis
GDT	Geometric Dimensioning and Tolerancing
GSE	Ground Support Equipment
ICD	Interface Control Document
JAXA	Japan Aerospace Exploration Agency
M&P	Materials and Processes
MIUL	Materials and Processes Identification and Usage List
MPR	Monthly Program Reviews
MR	Management Reserve
MSFC	Marshall Space Flight Center
MUA	Material Usage Agreement
NASA	National Aeronautics and Space Administration
NDT	Non-Destructive Testing
QAP	Quality Assurance Plan
SBU	Sensitive But Unclassified
SLS	Space Launch System
SOO	Statement of Objectives
SSP	System Safety Plan
STEP	Standard for the Exchange of Product
VCR	Verification Compliance Report

APPENDIX B

Data Products Document (DPD)

B.1 Contents

This Appendix contains the Data Requirements Descriptions (DRDs) for the various deliverable products referenced in the SOO.

B.2 Applicable Documents

The applicable and reference documents for the MB-60 system requirements are a subset of those established for the CDOD. No additional list is necessary.

B.3 Data Types

There are three data types to be used for the purposes of this DPD. The differences associated with data types are manifested in whether and how documents are to be treated by NASA. The data types are as follows:

- Type 1 – Review by and concurrence from NASA is required to ensure that, in the end, the objectives of the overall project are fulfilled. Changes to a Type 1 data product need to be formally tracked as product revisions.
- Type 2 – This data type is similar to Type 1 except that review and concurrence cycle for NASA is time-limited to 45 days. If after that period NASA has made no comment, then concurrence is assumed. Changes to a Type 2 data product need to be formally tracked as product revisions.
- Type 3 – While these products do require delivery, explicit or default NASA concurrence is not necessary.

B.4 Data Requirements List

<u>DRD</u>	<u>Data Type</u>	<u>Title</u>
DE-001	2	Structural Assessment Plan
DE-002	3	Structural Strength and Fatigue Analysis Reports
DE-003	2	Fracture Control Plan
DE-004	3	Fracture Control Reports
DE-005	2	Materials and Processes Selection, Implementation, and Control Plan
DE-006	3	Material and Process Identification and Usage List (MIUL)
DE-007	2	Material Usage Agreements (MUAs)
DE-008	3	Thermal Design Data Book
DE-009	2	Propulsion System Development Plan
DE-010	3	Engine System Test Reports
DE-011	3	Product Definition Data and Associated Lists
SE-001	1	Engine System Specification
SE-002	2	Verification Compliance Reports
SE-003	2	Configuration Management Plan
SQR-001	2	System Safety Plan (SSP)
SQR-002	2	Quality Assurance Plan (QAP)
SQR-003	2	Hazards Analysis
SQR-004	2	Failure Modes and Effects Analysis and Critical Items List

DRD: DE-001

Title: Structural Assessment Plan

Data Type: 2

Purpose: To document plans, processes, and factors demonstrating compliance with requirements for strength and fatigue analyses, tests, and structural assessment.

Submission

Schedule: Initial submission for Preliminary Design Review. Update for Critical Design Review. Update after that as necessary.

Scope / Contents:

The Structural Assessment Plan will be prepared in accordance with NASA-STD-5012 and describes compliance with the structural strength program requirements. The plan will identify the organization responsible for the structural analyses, tests, and assessment tasks; define satisfactory results; and include a schedule for completion. The plan will distinguish between flight and development hardware, identify components that require design verification tests and proof tests, specify appropriate test levels and environments, and state the means of correlating test data with analyses.

Format: JAXA format is acceptable.

DRD: DE-002

Title: Structural Strength and Fatigue Analysis Reports

Data Type: 3

Purpose: To document engine component strength and fatigue analysis and a structural analysis database used for development of the engine.

Submission

Schedule: Initial submission as draft/preliminary at Preliminary Design Review. Update for Critical Design Review. Update after that as necessary to ensure reports remain accurate for final closeout milestone.

Scope / Contents:

Strength and fatigue analyses are documented to demonstrate that strength and fatigue requirements have been met consistent with the processes and factors established in DE-001, *Structural Assessment Plan*. Preliminary strength and fatigue analyses presented at the Preliminary Design Review will assure the structural integrity of major structural elements and the credibility of mass calculations. Analyses provided in support of the Critical Design Review will substantiate the structural integrity of detailed parts and provide the basis for approval of drawings. Analyses provided in support of verification will fully substantiate the structural integrity of each detailed part in its final design configuration and subject to validated mission induced environments.

Strength and fatigue analyses for structural components will verify the capability of the hardware to withstand worst case design loads. The strength and fatigue analyses reports will identify such items as geometric description of each component, drawing or part number, identification of all applied loads, type of material and applicable strength and fatigue allowables, environments and effects, proper identification of reference inputs into the analyses, and a summary of calculated margins of safety and life predictions. When computer analyses, including finite element analyses are used, deliverable information will include a description of the analyses with applicable geometry, dimensions, loads, other boundary conditions, annotated input data file(s), plots of model geometry, and results. This information will be sufficient to recreate the analysis if necessary.

Format: JAXA format is acceptable.

DRD: DE-003

Title: Fracture Control Plan

Data Type: 2

Purpose: To document plans, processes, and factors demonstrating compliance with requirements for fracture control.

Submission

Schedule: Initial submission for Preliminary Design Review. Update for Critical Design Review. Update after that as necessary.

Scope / Contents:

The Structural Assessment Plan will be prepared in accordance with NASA-STD-5019 and describes compliance with the fracture control requirements. The plan will define the elements of the fracture control program and the responsibilities for managing them.

Further information and examples are found in NASA-HDBK-5010.

Format: JAXA format is acceptable.

DRD: DE-004

Title: Fracture Control Reports

Data Type: 3

Purpose: To document engine compliance to fracture control requirements.

Submission

Schedule: Initial submission for Critical Design Review. Update after that as necessary to ensure reports remain accurate for final closeout milestone.

Scope / Contents:

The Fracture Control Reports will be prepared in accordance with the processes and factors established in DE-003, *Fracture Control Plan*, and will provide the fracture control analyses results that demonstrate that the fracture control requirements are met. The report will include a list of parts and their disposition for fracture control. In addition to the fracture control analysis required for non-fracture critical components, the report will include for each fraction-critical part a Fracture Control Summary Report and Fracture Control Analysis Report consistent with the descriptions provided in NASA-STD-5019.

Format: JAXA format is acceptable.

DRD: DE-005

Title: Materials and Processes Selection, Implementation, and Control Plan

Data Type: 2

Purpose: To define the objectives, procedures, logic, and management controls for the materials and processes (M&P) selection, implementation, verification, and control program.

Submission

Schedule: Initial submission for Preliminary Design Review. Update for Critical Design Review. Update after that as necessary.

Scope / Contents:

The Materials and Processes Selection, Implementation, and Control Plan will establish procedures to ensure that all M&P comply with the requirements of NASA-STD-6016. The plan will describe the activities involved in the identification, evaluation, documentation, and reporting of M&P usage in engine hardware. The method for materials control and verification of subcontractors and vendors will be included in this plan as well. As a minimum and as applicable, the plan will address the following:

Conformance – Address each applicable paragraph of NASA-STD-6016 and describe the method of implementation and degree of conformance for each applicable requirement. If tailoring of the requirements is planned or necessary, the hardware developer will submit alternate approaches to NASA-STD-6016 in this plan.

Organization – Identify the individual or group who will be responsible for review and approval of all M&P specified prior to release of engineering documentation.

Usage Evaluation - Document M&P used in accordance with the Material and Process Identification and Usage List (MIUL) requirements of NASA-STD-6016 and the comparison of test data to selection requirements.

Testing – Present the logic, procedures, and data documentation for any proposed test program to support materials screening and verification testing.

DRD: DE-005 (Continued)

Scope / Contents: (Continued)

Material Usage Agreement (MUA) Procedures – Present the logic, procedures, and documentation involved in identifying and approving materials/processes as indicated in NASA-STD-6016. This includes those that do not meet the established requirements but are proposed for use due to lack of replacement materials/processes or other considerations.

New Technology – Identify areas of new test technology or technique improvement for consideration.

Approved Materials List (AML) – Issue and maintain an Approved Materials List from which all materials, including fasteners, will be selected. The selection of materials will be based on consideration of cost, availability, reliability, and compatibility with the hardware environment.

Approved Processes List (APL) – Issue and maintain an Approved Processes List from which all processes will be selected. In instances where cost, skill or equipment limitations make the selection of a subcontractors processes more economical, the processes will be submitted for approval prior to fabrication. Copies of all approved subcontractor and hardware developer process specifications will be maintained and be available for review.

Corrosion Prevention, Control and Protective Finish Plan – Issue and maintain a corrosion prevention, control and protective finish plan addressing the following as a minimum:

- Environmental corrosion prevention and control measures for all program components, including definition of all environments, test and verification requirements.
- Selection methodology with supporting data for the selection of M&P used in corrosion prevention and control.
- Finish specifications, delineating the protective finishes, including cleaning and surface treatment, will be developed and available for review by NASA.

DRD: DE-005 (Continued)

Scope / Contents: (Continued)

Forging Plan – Issue and maintain forging plan in accordance with NASA-STD-6016 showing locations and numbers of specimens to be excised from the first production equivalent size forging. The forging plan will include production forging verification and control measures. In the event of forging process changes, the plan will include supporting rationale and/or tests to demonstrate the required design material properties and grain flow patterns at control areas.

Casting Plan – Issue and maintain a casting plan in accordance with NASA-STD-6016 showing locations and numbers of specimens to be excised from the first production equivalent size casting, including production casting verification and control measures. In the event of casting process changes, the plan will include supporting rationale and/or tests to demonstrate the required design material properties and grain size at control areas.

Adhesive Control and Operator Certification Plan - Issue and maintain an adhesive control plan and adhesive bonding operator certification plan.

Format: JAXA format is acceptable.

DRD: DE-006

Title: Material and Process Identification and Usage List (MIUL)

Data Type: 3

Purpose: To identify and document materials and processes (M&P) usages throughout the engine (excluding electronics).

Submission

Schedule: Initial submission for Critical Design Review. Update after that as necessary to ensure list is accurate for final closeout milestone.

Scope / Contents:

The MIUL will contain the content as specified in NASA-STD-6016. Ideally, the MIUL will be documented in an electronic, searchable parts list of separate database.

Format: JAXA format is acceptable.

DRD: DE-007

Title: Materials Usage Agreements (MUAs)

Data Type: 2

Purpose: To identify and document materials and processes (M&P) usages that are technically acceptable but do not meet the requirements of DE-005, *Materials and Processes Selection, Implementation, and Control Plan*.

Submission

Schedule: Initial submission for Critical Design Review. Revised or updated after that as necessary.

Scope / Contents:

The MUAs will contain the content as specified in NASA-STD-6016 and will include all technical information required to justify the application. MUAs will be submitted as described below:

Category I MUAs are those that involve material/processes usage that could affect the safety of the mission, crew, or vehicle or affect the mission success, but must be used for functional reasons. Approval by the responsible NASA is required.

Category II MUAs are those that involve material/processes usage that fails a screening of Material and Processes requirements and is not considered a hazard in its use application but for which no Category III rationale code exists. Approval by the responsible NASA is required.

Category III MUAs are those that involve materials or processes that have not been shown to meet these requirements but have an approved rationale code listed in Appendix C of NASA-STD-6016. They are evaluated and determined to be acceptable at the configuration/part level. Category III MUAs will be reported in the Materials Identification and Usage List (MIUL) system utilizing the approved rationale codes in Appendix C. No MUA form is submitted and no further approval required beyond identification.

Format: Use format compatible with that provided in NASA-STD-6016.

DRD: DE-008

Title: Thermal Design Data Book

Data Type: 3

Purpose: To documents all details of the engine thermal design.

Submission

Schedule: Initial submission for Preliminary Design Review. Update for Critical Design Review. Update after that as necessary based upon information learned during test program.

Scope / Contents:

The Thermal Design Data Book will be a compilation of engine design criteria, thermal environments, materials and material properties, a summary of component thermal response and thermal protection design thickness to meet requirements. Detailed thermal analysis assumptions (properties, environments and geometries), thermal model general descriptions and thermal analysis results will be documented in separate reports, but listed as references. The purpose of the Thermal Design Data Book is to present, in abridged form, information from these detailed analytical reports necessary for the reader to understand the thermal response of the engine subjected to induced thermal environments for a design mission trajectory.

Material thermal physical properties to be documented will include temperature dependent density, conductivity, and specific heat. Thermal protection surface optical properties characterization will include spectral absorptivity, emissivity, and transmissivity, if applicable. Material thermal physical properties will be documented in a subsection of the document reserved for thermal physical properties data.

References to the assumed natural and induced environments used will be documented. Provide the thermal model(s) and any necessary associated files in electronic format. Reference will be made to any Computer Aided Design (CAD) drawings used in thermal modeling. Provide drawings of hardware as implemented in thermal models.

Format: JAXA format is acceptable.

DRD: DE-009

Title: Propulsion System Development Plan

Data Type: 2

Purpose: To establish and delineate a cohesive and comprehensive approach for developing the propulsion system.

Submission

Schedule: Initial submission for Preliminary Design Review. Update for Critical Design Review. No further updates after that.

Scope / Contents:

The intent of the Propulsion System Development Plan is to provide an early overview of the complete plan for fulfilling the project development goals. It provides the single-document description of what is to be accomplished and how. At a minimum it will include the following information:

- It describes the full development cycle schedule through the design reviews, other key milestones, and a description of the endpoint goals and objectives.
- It catalogs the key assumptions, ground rules, and constraints that will shape the decision criteria throughout the development process.
- It describes the process to be followed with regards to requirements decomposition, subsystem and component resources allocation, trades studies, component selection logic, and system integration planning.
- It describes the planned development, usage, and validation for key analytical modeling tools to be used throughout the design, development, and verification processes.
- It describes the planned iterative process of hardware design, analysis, validation, and integration.
- It describes subsystem, subscale, or prototype development testing activities necessary to ensure robust design and development prior to full-scale system testing. Facilities for any such testing will be identified.
- It describes the hardware manufacturing path and logistics by way of fabrication or procurement through to assembly for both subsystem development hardware and full-scale system hardware.
- It describes the scope for planned system-level testing including number of units to be tested, spare hardware requirements, and key objectives to be demonstrated. Facilities for any such testing will be identified.

Format: JAXA format is acceptable.

DRD: DE-010

Title: Engine System Test Reports

Data Type: 3

Purpose: To document the as-run test matrix, test procedures, as-built test article, test results, data analysis, and conclusions for the engine system test program

Submission

Schedule: After completion of test series. To be negotiated in detail further.

Scope / Contents:

The Engine Test Reports will include a detailed as-built test article description; the as-run test matrix (including test article configurations, test parameters, test durations, and number of tests) with detailed rationale for all deviations from the planned matrix; detailed descriptions of the instrumentation and data acquisition systems; detailed descriptions of as-built test setup; detailed presentation of test results, including a detailed assessment showing how the results have satisfied each objective enumerated in the test plan; and the test conclusions.

Format: JAXA format is acceptable.

DRD: DE-011

Title: Product Definition Data and Associated Lists

Data Type: 3

Purpose: To provide engineering data to define the design to the extent required to support manufacturing, test, and logistics

Submission

Schedule: Initial submission for Preliminary Design Review. Update for Critical Design Review. Update for final closeout milestone.

Scope / Contents:

Product Definition Data and Associated Lists documentation consists of engineering drawings, 3D model-based digital data sets, and all associated lists, that are sufficient to depict the detailed design configuration definition of all systems, subsystems, and components. These items are to include but are not limited to avionics, pneumatic, fluid, and interfaces to ground support equipment.

Requirements:

- a. Part I - Technical Data Packages will meet the requirements for Product Drawings and Associated Lists specified in MIL-DTL-31000 to define end items, elements and/or all components and assemblies as necessary for the manufacture, test, inspection, operations and logistic support of the system. This definition will:
 - 1. Reflect the end-product at its current level of design maturity.
 - 2. Provide the engineering data for logistics support products.
 - 3. Provide the necessary data to permit manufacture and/or acquisition of items identical to the original item(s).
 - 4. Engineering Product Definition will satisfy the requirements of ASME Y14.100, as supplemented by Appendices B, C, D, and E and additional referenced and sub-tiered standards of the ASME Y14.x series, particularly ASME Y14.24, ASME Y14.34, and ASME Y14.35. Three-dimensional model-based digital data sets, if used instead of or in addition to drawings, will satisfy these same standards except as modified and supplemented by ASME Y14.41-2003. These drawings and/or data sets will document directly or by reference the following:

DRD: DE-011 (Continued)

Scope / Contents: (Continued)

- (a) Details of unique processes (i.e., not published or generally available to industry) when essential to design and manufacture.
 - (b) Performance ratings.
 - (c) Dimensional and tolerance data (Geometric Dimensioning and Tolerancing (GDT) will be required between all external and major internal interfaces).
 - (d) Critical manufacturing processes and assembly sequences
 - (e) Mechanical, fluid and electrical connections by means of both scaled assembly views and schematic diagrams as necessary for a complete definition. (See also Part II.)
 - (f) Physical characteristics, including form and finish.
 - (g) Detailed material identification, including heat treatment and protective coatings.
 - (h) Inspection, test, and evaluation criteria.
 - (i) Equipment calibration requirements.
 - (j) Quality assurance requirements.
 - (k) Hardware identification marking requirements.
 - (l) Requirements for reliability, maintainability, environmental conditions, shock, and vibration testing and other operational or functional tests.
 - 5. Limited rights-in-data items - Product definition for items which NASA does not have unlimited rights in data will specify the form, fit, and function requirements of the item and conform to the requirements for a control drawing as defined in ASME Y14.24.
 - 6. Export control limitation requirements - Technical Data Packages will contain the appropriate control markings on 2D drawings as well as graphically displayed within the three-dimensional model-based digital data set.
- b. Part II - Cable interconnect diagrams (CID's), electrical system schematics, and wiring lists. Cable interconnect diagrams, electrical system schematics, wiring lists, and fluid system schematics will be prepared in accordance with ASME Y14.24 and ASME Y14.41. Part I data sets will be utilized to the maximum extent possible in providing this design definition. The data sets will include the following:
- 1. Cable interconnect diagrams will show graphically the arrangement of external electrical cabling which interconnects electrical assemblies and/or equipment. The CID will show all cable runs and terminations; each cable will be identified by reference designation number. The connector short sign will be identified.

DRD: DE-011 (Continued)

Scope / Contents: (Continued)

2. Electrical system schematics will illustrate and describe circuit items with symbols placed such that a circuit may be traced from item to item in the sequence of its function. The placement and arrangement of these circuits will follow a logical sequence of presentation to provide a clear description of the distribution.
3. Component Level Documentation - Schematics and/or wiring lists for components, including interconnecting cable harnesses, will be provided.
4. Overall Grounding Documentation - The grounding schematic will show the details of all grounds and power returns from source to loads. All connections will be shown. It will also show details of all Electrical Ground Support Equipment interconnections to facility and safety grounds.
5. The Fluid system schematic will illustrate and describe all components with symbols and flow designators such that the fluid system may be traced from component to component (such as pumps, valves, meters, regulators, and filters). The schematics will document the range requirements (flow, temperature, and pressure) for all component external interfaces and line sizes. The placement and arrangement of these components will follow a logical sequence of presentation to provide a clear description of the flow of fluids in the system. The schematics will reference engineering datasets and associated lists for configuration details.

Format: Format for product definition drawings will be in accordance with ASME Y14.100 and provided in CGM (Computer Graphics Metafile) format. Model-based product definition digital data sets will be in accordance with ASME Y14.41 and provided in Low End Viewer, native CAD or neutral STEP (Standard for the Exchange of Product Model Data) format. Simplified drawings that require a 3D solid model to complete the product definition will also include a validated STEP file in the data set. Preferred authoring formats are Pro/Engineer and Mentor Graphics; however, delivery of the native CAD is not required. Alternate formats may be acceptable upon negotiation. Product definition data will utilize JAXA CAGE Code, drawing formats, and document numbers.

DRD: SE-001

Title: Engine System Specification

Data Type: 1

Purpose: To document the performance, functional, operational, and physical design requirements and design standards of the engine system and the associated top-level verification requirements.

Submission

Schedule: Initial submission for System Requirements Review (design requirements only).
Update for Preliminary Design Review (complete document). Update for Critical Design review and as necessary after that.

Scope / Contents:

The Engine System Specification provides the performance, functional, physical characteristics, and operational requirements, and design standards provided consistent with the established requirements. Associated top-level verification methods, requirements, and success criteria are provided for all design requirements.

The System Specification will be traceable to the MB-60 Element Requirements Document (ERD – see Appendix C of the CDOD), and using the standards of MIL-STD-961 as guidelines.

Format: JAXA format is acceptable.

DRD: SE-002

Title: Verification Compliance Reports (VCRs)

Data Type: 2

Purpose: To report the results of the planned verification activities with respect to the identified verification success criteria.

Submission

Schedule: As verification activities are completed for the design requirements. No later than for the final closeout milestone.

Scope / Contents:

The VCR will define for each requirement, the method(s) of verification and corresponding compliance data for each method defined. The VCR will provide the actual data or will provide a reference to the location of the actual data that shows compliance with the requirement, including the specific locator (document title and number, page number, paragraph number, etc.) needed to find the applicable portion within the data. The VCR will also specify any non-compliance with the requirements, referencing the non-compliance report, and the re-verification of the requirement.

The Verification Compliance Report will summarize the results of all verification activities and special tests associated with the given requirement, and provide the accepted evidence of the verification. The reports are prepared in a manner that relates each reported item to a verification requirement. The verification report includes as appropriate:

- a. List of all related released documents (test plans, reports, analysis reports, etc.)
- b. Verification objectives and degree to which they were met
- c. Description of verification activity
- d. Test configuration and differences from flight configuration
- e. Summary of results of tests
- f. Summary of results of each analysis
- g. Summary of test performance data, plots, pictures (as appropriate)
- h. Assessment of applicability of any data used for this verification activity that was generated as part of a previous verification activity
- i. Description of deviations from nominal results, failures, approved anomaly reports.

DRD: SE-002 (Continued)

Scope / Contents: (Continued)

- j. Corrective actions, and re-test activity
- k. Summary of non-conformance/discrepancy reports including dispositions
- l. Conclusion and recommendations relative to success of verification activity
- m. Signature of identified responsible points of contact indicating that the success criterion has been satisfied.
- n. As-run procedures.

Format: JAXA format is acceptable.

DRD: SE-003

Title: Configuration Management Plan

Data Type: 2

Purpose: To describe the method for accomplishing the configuration management requirements.

Submission

Schedule: Initial submission as draft/preliminary for the System Requirements Review.
Update for the System Definition Review. Update after that as necessary.

Scope / Contents:

The Configuration Management Plan will be prepared in accordance with MSFC-STD-3394 and provide the information defined in Appendix A of that standard. The Configuration Management Plan will provide the approach for implementing a structured and disciplined configuration management program for data products, hardware, and associated equipment.

Format: JAXA format is acceptable.

DRD: SQR-001

Title: System Safety Plan (SSP)

Data Type: 2

Purpose: To define the objectives, responsibilities, and methods to be used for overall system safety program conduct and control.

Submission

Schedule: Initial submission as draft/preliminary for the System Requirements Review.
Update for the System Definition Review. Update after that as necessary.

Scope / Contents:

The System Safety Plan (SSP) will address and meet the safety program requirements (Section 4) in SLS-RQMT-014 considering this development effort to be analogous to an element development effort within the SLS Program. The SSP will address requirements for safety organization participation in design, safety, and readiness reviews.

Format: JAXA format is acceptable.

DRD: SQR-002

Title: Quality Assurance Plan (QAP)

Data Type: 2

Purpose: To define the objectives, responsibilities, and methods to be used for overall quality assurance program conduct and control.

Submission

Schedule: Initial submission as draft/preliminary for the System Requirements Review.
Update for the System Definition Review. Update after that as necessary.

Scope / Contents:

The Quality Assurance Plan will address and meet the quality program requirements (Section 6) in SLS-RQMT-014 considering this development effort to be analogous to an element development effort within the SLS Program. The QAP will include detailed task requirements for the quality assurance task as tailored for this program. It will address requirements for safety organization participation in design, safety, and readiness reviews.

Problem reporting processes established by the QAP will meet the requirements in SLS-RQMT-014, Appendix B.

Format: JAXA format is acceptable.

DRD: SQR-003

Title: Hazards Analysis

Data Type: 2

Purpose: To reduce safety risk and to establish the acceptable risk of the program through systematic process to identify single or combinations of failures that can result in hazards through an iteration process.

Submission

Schedule: Initial submission as draft/preliminary for the Preliminary Design Review.
Update for the Critical Design Review. Update after that as necessary to ensure accurate analysis for final closeout milestone.

Scope / Contents:

Hazard Analyses will be prepared in accordance with SLS-RQMT-015 considering this development effort to be analogous to an element development effort within the SLS Program. The Hazards Analysis will identify hazards and evaluate risk, by identifying single failures and combinations of failures that result in hazards to the vehicle/elements or crew, and the analyses also establish verification methods.

A Fault Tree Analysis will be developed in parallel and in support of design, development, and operational phases of the program. Multiple Fault Tree Analyses will be developed to support the overall safety analysis in parallel and in support of design, development, and operational phases of the program.

Format: Hazard Analysis will be generated in electronic format in accordance with SLS-RQMT-015.

DRD: SQR-004

Title: Failure Modes and Effects Analysis (FMEA) and Critical Items List (CIL)

Data Type: 2

Purpose: The purpose of the FMEA is to identify and document the possible failures modes and causes of each hardware item of a subsystem/system, the worst case effect of such failures for each mission phase, and assigns criticality.

The purpose of the CIL is to identify and document the list of critical failure modes of item(s) in each subsystem/system with potential worst case effects.

Submission

Schedule: FMEA – Initial submission of draft/preliminary functional FMEA for the System Definition Review. Update FMEA for the Preliminary Design Review and Critical Design Review. Update after that as necessary to ensure accurate analysis for final closeout milestone.

CIL – Initial submission at Critical Design Review. Update after that as necessary to ensure accurate information for final closeout milestone.

Scope / Contents:

The FMEA information is vital for understanding and facilitating design efforts, potential design improvements and understanding potential design constraints due to system interactions, reliability and maintainability analysis.

The CIL provides details of relevant design features, testing and inspections processes and controls, as applicable to the failure mode, to mitigate/minimize the risk. CIL retention rationale bridges the gap in the design, test/verification requirements, inspection and process controls.

The FMEA/CIL will be prepared in accordance with SLS-RQMT-016 considering this development effort to be analogous to an element development effort within the SLS Program.

Format: FMEA and CIL worksheets will be generated in electronic format in accordance with SLS-RQMT-016.

APPENDIX C

Engine Requirements Document (ERD)

C.1 Introduction

The purpose of this document is to establish for NASA Marshall Space Flight Center, Space Launch System (SLS) Program Engines Element Office the technical requirements for the MB-60.

Overall, the requirements set is far more abbreviated than the recent analogous collections for other engines. Part of the reason for this is the fact that engine control system considerations are not included. Also, however, it is the conscious intent here to be as concise as possible on the requirements side to minimize bureaucratic overhead thereby allowing for a constructive collaboration.

C.2 Documents

The applicable and reference documents for the MB-60 system requirements are a subset of those established for the CDOD. No additional list is necessary.

C.3 System Design Requirements

This section contains the essential technical requirements that apply to the performance, function, and design of the MB-60. This section is intended to indicate, as definitively as practicable, the minimum requirements that the configuration item, the MB-60, must meet to fulfill its intended purpose. The technical requirements define what the MB-60 must do or qualities that the MB-60 must have. The requirements of this section will be verified as part of the engine development effort.

The convention used in this document which indicates requirements, goals, and statements of facts is as follows:

- Shall – Used to indicate a binding requirement
- Should – Used to indicate a desired goal
- Will, is, or are – Used to indicate a statement of fact

Every design requirement containing a "shall" is binding and must be verified. Goals and statements of fact are non-binding.

Also, rationale statements are included for all of the requirements. They are located below the binding requirement and are identified by *Italics font*. The rationale statements are intended to provide clarification, justification, purpose, and/or origin of the requirement. It is important to note that the rationale statements are not binding and only provide supporting information. In the event there is an inconsistency between the requirement and the rationale statement, only the requirements themselves will ultimately be binding and take precedence.

C.3.1 Engine Description

The MB-60 is a liquid-hydrogen/liquid-oxygen rocket engine intended to provide in-space propulsion. It is high-performance to fulfill projected mission requirements and it is highly reliable to meet the needs for human space flight.

C.3.2 Engine Qualities

C.3.2.1 Performance

[R.JN1.2101] MB-60 Nominal Vacuum Thrust

The MB-60 shall provide nominal vacuum thrust of 60,000 lbf when operating at nominal engine inlet conditions.

[R.JN1.2102] MB-60 Thrust Precision

The MB-60 shall operate within a tolerance band of $\pm 3\%$ [TBR] around the primary mode nominal vacuum thrust value at nominal engine inlet conditions.

[R.JN1.2103] MB-60 Throttling

The MB-60 shall provide throttling to a single set point not less than 75% [TBR] of nominal thrust.

[R.JN1.2104] MB-60 Vacuum Specific Impulse

The MB-60 shall provide a minimum vacuum specific impulse of 462 [TBR] seconds when operating at corrected nominal thrust, mixture ratio, and engine inlet conditions.

[R.JN1.2105] MB-60 Nominal Mixture Ratio

The MB-60 shall operate at a nominal overboard mixture ratio of 5.40 [TBR] at nominal engine inlet conditions.

[R.JN1.2106] MB-60 Mixture Ratio Precision

The MB-60 shall operate within a tolerance band of $\pm 2\%$ [TBR] around the nominal mixture ratio value at nominal engine inlet conditions.

Section C.3.2.1 Notes:

The following conditions are to be considered nominal inlet conditions for MB-60 for the purposes of the above performance requirements:

- Liquid Oxygen Inlet Pressure 45 [TBR] psia
- Liquid Oxygen Inlet Temperature 164.5 [TBR] R
- Liquid Oxygen Purity $\leq 98.5\%$
- Liquid Hydrogen Inlet Pressure 37 [TBR] psia
- Liquid Hydrogen Inlet Temperature 37.2 [TBR] R

C.3.2.2 Functionality

[R.JN1.2201] MB-60 Start

The MB-60 shall perform a controlled engine start upon command to directly any planned steady-state, mainstage power level.

[R.JN1.2202] MB-60 Shutdown

The MB-60 shall perform controlled engine shut-down operations upon command from any power level.

[R.JN1.2203] MB-60 Mission Profile

The MB-60 shall provide for as many as five engine start, mainstage, and shutdown sequences within a single mission.

[R.JN1.2204] MB-60 Minimum Net Positive Suction Pressure

The MB-60 shall operate at mainstage with the following minimum net positive suction pressure values at the engine inlet:

- Hydrogen Propellant Inlet 8 [TBR] psi
- Oxygen Propellant Inlet 15 [TBR] psi

[R.JN1.2205] MB-60 Gimbal Flexure

The MB-60 shall provide engine system flexure relative to a fixed thrust mount such that a five-degree circular [TBR] gimbal pattern can be described by the thrust vector.

[R.JN1.2206] MB-60 Pressurization Flow

The MB-60 shall provide gaseous hydrogen and gaseous oxygen output flows for stage propellant tank pressurization.

Section C.3.2.2 Notes:

The assumed ambient start and shutdown conditions are to be considered on-orbit or in-space at near-vacuum conditions.

C.3.2.3 Characteristics

[R.JN1.2301] MB-60 Mass

The MB-60 shall not exceed maximum dry mass of 1,300 [TBR] lbm including associated accessories.

[R.JN1.2302] MB-60 Dimensions

The MB-60 shall not exceed maximum static dimensions of 130 [TBR] inches in length.

[R.JN1.2303] MB-60 Life – Starts

The MB-60 shall provide hardware life without component refurbishment for at least seven [TBR] engine starts after engine delivery.

[R.JN1.2304] MB-60 Life – Seconds

The MB-60 shall provide hardware life for at least 3,500 [TBR] seconds after engine delivery without component refurbishment.

[R.JN1.2305] MB-60 Continuous Firing Duration

The MB-60 shall provide at least 800 seconds of continuous hot-fire operation.

[R.JN1.2306] MB-60 Reliability

The MB-60 shall have a mean risk value of 1 in 4,000 [TBR] for loss of mission due to an engine root-cause failure during a single engine firing.

C.3.3 Design and Construction

[R.JN1.3301] MB-60 Strength and Life Design

The MB-60 shall meet the intent of the requirements of NASA-STD-5012 for strength and life assessments for the engine.

[R.JN1.3302] MB-60 Mechanism Design

The MB-60 shall meet the intent of the requirements in Sections 1 through 4 of NASA-STD-5017 for design and development standards for mechanisms.

[R.JN1.3303] MB-60 Fracture Control

The MB-60 shall meet the intent of the requirements of NASA-STD-5019 for fracture control requirements for manned space flight systems.

[R.JN1.3304] MB-60 Materials and Processes

The MB-60 shall meet the intent of the requirements of NASA-STD-6016 with regards to materials and processes used for engine design and fabrication.

Section C.3.3. Notes:

See Section 1.3 of the CDOD for a discussion regarding compliance to imposed standards.

C.3.4 Interfaces and Environments

[R.JN1.3401] MB-60 Performance and Induced Environments

The MB-60 shall meet its requirements during and after exposure to the induced, external environments as specified in [TBD].

C.4 Requirements Verification

This section is incomplete at this time. It will be completed collaboratively between JAXA and NASA prior to the MB-60 System Definition Review.